

# Use of Gas Electron Multiplier (GEM) Detectors for an Advanced X-ray Monitor

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## ABSTRACT

We describe a concept for a NASA SMEX Mission in which Gas Electron Multiplier (GEM) detectors, developed at CERN, are adapted for use in X-ray astronomy. These detectors can be used to obtain moderately large detector area and two-dimensional photon positions with sub mm accuracy in the range of 1.5 to 15 keV. We describe an application of GEMs with xenon gas, coded mask cameras, and simple circuits for measuring event positions and for anticoincidence rejection of particle events. The cameras are arranged to cover most of the celestial sphere, providing high sensitivity and throughput for a wide variety of cosmic explosions. At longer timescales, persistent X-ray sources would be monitored with unprecedented levels of coverage. The sensitivity to faint X-ray sources on a one-day timescale would be improved by a factor of 6 over the capability of the RXTE All Sky Monitor.

**Keywords:** X-ray detectors, gas electron multipliers, coded masks, X-ray astronomy, all-sky monitors

## 1. INTRODUCTION

X-ray astronomy is our primary window to the portion of the Universe characterized by high temperatures and explosive behavior. As one progresses from visible light to the extreme UV, our view of the cosmos beyond the local region in the Galaxy is increasingly attenuated by interstellar absorption. However, as we approach 1 keV and the X-ray band, our long-range view becomes clear again. Since X-ray sources generally radiate fewer photons at higher energy, it is no wonder that X-ray astronomy missions historically favor the energy range of 1-10 keV.

Detectors with two-dimensional imaging capability are a workhorse for X-ray astronomy. In the energy range of 1-10 keV, there are two primary types of position-sensitive detectors flown on space-borne missions: gas detectors and solid-state charge-coupled devices (CCDs).

Gas detectors include both “standard” proportional counters and gas-scintillation detectors. Position-sensitive versions of these were used for the Einstein IPC,<sup>1</sup> the ROSAT PSPC,<sup>2</sup> and the ASCA GIS<sup>3,4</sup> for the purpose of recording with modest spectral resolution the images formed by focusing X-ray telescopes. Gas detectors are also used to record the X-ray shadows of coded masks for current wide-angle instruments, including the All Sky Monitor<sup>5</sup> of the *Rossi* X-ray Timing Explorer (RXTE), the Wide Field Camera<sup>6</sup> on the *BeppoSAX* satellite, and the Wide-Field X-ray Monitor<sup>7</sup> on the HETE-II Mission, to be launched in mid-2000. The dimensions of these detectors are generally in the range of 8–25 cm, and the position resolution is roughly 0.2–2 mm, sometimes with degraded resolution along the second axis. Gas mixtures with argon and/or xenon as the primary constituent provide very good quantum efficiency for the detection of 1-10 keV X-rays, and pulse height analysis of X-ray events provides modest spectral resolution ( $\Delta E/E \sim 0.08 - 0.15$  at 6 keV). There are a variety of methods for measuring positions of incident X-ray photons; for the proportional counter detectors these include charge division along resistive anodes, pulse rise time differences, and charge collection by discrete wires, by conductive strips on an insulating substrate, or by “pick-up” strips on printed circuit boards. Both types of gas detectors routinely provide time resolution better than 1 ms.

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Recently, X-ray CCDs have been used in imaging spectroscopy missions such as ASCA (i.e., in the SIS instrument), the Chandra X-ray Observatory (ACIS<sup>8</sup>), and Newton-XMM (EPIC). CCDs will also be used in the Soft X-ray Cameras (SXC) on HETE II, where they will act as one-dimensional position-sensitive detectors in coded-aperture cameras. Generally, CCD detectors provide superior position resolution, in the range of 10–50  $\mu\text{m}$ . CCDs offer improved spectral resolution (e.g.  $\Delta E/E \sim 0.02$  at 5 keV for the HETE-SXC). They also make it easier to extend the sensitive energy range of the instrument down to  $\sim 0.5$  keV, while the soft X-ray sensitivity in gas detectors is usually limited by the opacity of the entrance window (e.g. Be foil or coated polypropylene).

The use of CCDs in X-ray astronomy missions, however, has its own limitations and difficulties. The dimension of the active area (2–6 cm) is much smaller than the size of gas detectors. X-ray CCDs are currently expensive, and significant resources of power, mass, and volume are needed from the host spacecraft because of the requirements for sophisticated drive electronics and systems for cooling the detectors to very low temperatures. The pixel readout methods for current CCDs provide poor time resolution (typically  $\sim 1$  s) and impose saturation limits for bright sources. There is also susceptibility to performance degradation in space applications, due to radiation damage in the South Atlantic Anomaly or other high background regions.

Other types of detectors, with a range of capabilities for imaging, such as microchannel plate detectors and microcalorimeters, also have their place in the arsenal of detectors for X-ray astronomy, but have characteristics which limit their applicability for instruments which require imaging capability over a large area at reasonable cost. There are also new materials being developed for X-ray cameras, such as Cd-Zn-Te arrays and silicon strip detectors, which are expected to advance our capabilities in hard X-rays, e.g. 10–100 keV. Their limited performance below 5 keV makes it unlikely that these technologies will compete with gas counters or CCDs in the 0.5–10 keV band in the near future.

One may therefore conclude that there are clear tradeoffs between two types of detectors in the current state of the art of X-ray imaging in the main X-ray band. Where detector area or time resolution is a high priority, then the choice of a gas detector would have strong advantages. Missions in this category would include wide-field surveys and bright-source monitors. In the sections below, we describe a new type of gas detector that provides the opportunity for substantial improvements in the field of X-ray all-sky monitors. We outline how these detectors may be adapted for astronomy, and how a mission design for all-sky viewing would achieve major advances in science themes related to both explosive events at short timescale and monitoring functions at long timescales.

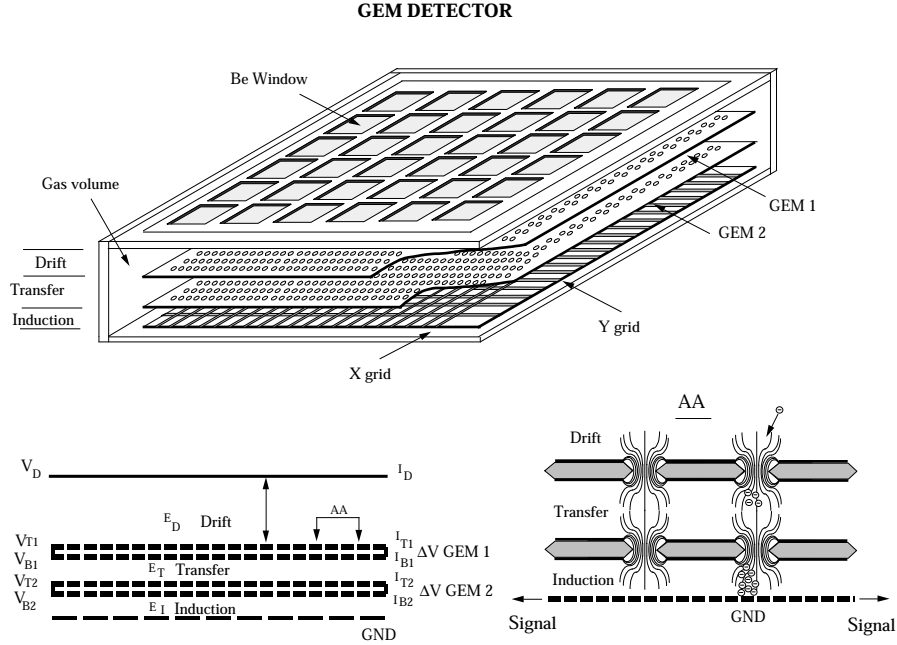
## 2. GEM DETECTORS FOR X-RAY ASTRONOMY

In the last few years, workers at CERN have developed the Gas Electron Multiplier (GEM) for use in gas-based particle and X-ray detectors.<sup>9,10</sup> The classical problem with gas counters is that a large detector with fine anode spacing (i.e. for position resolution) and high voltage (for soft X-ray sensitivity and good spectral resolution) encounters substantial risk of electrical breakdown due to the high electric fields close to the anodes. The GEM detectors improve this situation, essentially by working to decouple the stages of electron multiplication and charge collection, so that both functions are not performed by a single conductive array under high voltage.

A GEM foil is a sandwich consisting of thin conductive layers of, e.g., copper separated by a thin polymer film (e.g. 50  $\mu\text{m}$  kapton). The foil is perforated with regularly-spaced and precisely shaped small holes (e.g., 80  $\mu\text{m}$  diameter spaced with a 140  $\mu\text{m}$  pitch). In operation inside a detector, a voltage (350–500 V) is applied between the conductive layers. As illustrated in Figure 1, the electric field lines guide charged particles through the GEM holes, with minimal losses due to collisions with the foil. Electrons are accelerated in the strong fields within the GEM foil, producing secondary ionizations and charge multiplication in the usual manner.

Figure 1 also depicts the operation of a GEM foil in an X-ray detector. When a gas atom in the upper chamber is ionized by an incident X-ray, the initial ionization cloud drifts toward the GEM foil due to a potential difference between the detector window and the upper GEM layer. The electrons are vertically guided through the holes in one or more GEM layers, with charge multiplication in the high electric fields within each layer. The resulting electron cloud then drifts to the readout plane, where the charge is collected via one of several possible electrode configurations.

The GEM was initially developed for detectors that utilize a “microstrip gas counter” (MSGC). This detector utilizes plated conductive strips on an insulating substrate, like a printed circuit board, rather than a grid of self-supported wires. High voltage is applied between the conductors in the strip. An orthogonal strip or an array of



**Figure 1.** (top) Schematic view of a detector containing two GEM multiplication stages. (lower left) Schematic cross section of the detector with the window plane at the top and readout plane at the bottom. In this drawing, the window and detector body are at a high negative electrical potential and the readout plane has a potential near ground. (lower right) A magnified view showing the electric field configuration in and near holes in the GEM foils. Multiplication of free electrons and ions occurs within the strong field region inside the holes.

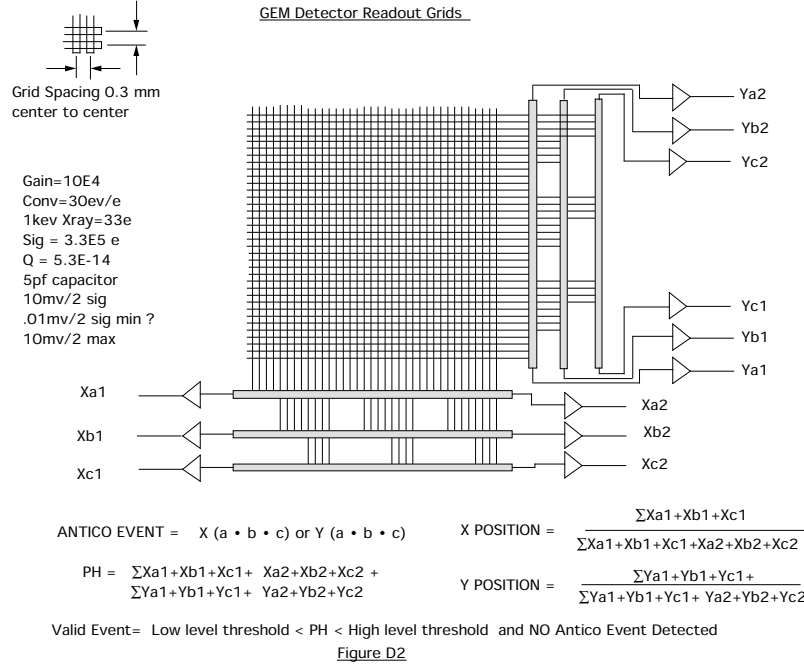
pickup electrodes serves to locate the event along the second axis. MSGC detectors (without GEMs) have flown on balloon flights,<sup>11</sup> and will be flown in the JEM-X instrument<sup>12</sup> on the INTEGRAL mission (2002).

The GEM was invented to provide the charge multiplication remote from the readout plane and to reduce the required high voltages on the microstrip readout. In the next development, a double layer of GEM foils was used to provide sufficient charge multiplication (e.g. gain factors of  $10^4$ ), so that the readout tracks could collect the charge without operating at high voltage.<sup>13</sup> GEM technology has been successful in achieving this goal in both double-GEM and GEM + MSGC configurations. These detectors are successfully used outside of CERN (e.g.<sup>14</sup>), and GEM + MSGC detectors are now in “mass production” assembly for the HERA-B experiment (CP symmetry violation in B mesons) at the DESY accelerator in Hamburg, Germany.<sup>15</sup>

We believe that GEM-based position-sensitive proportional counters with wireless conductive strip readout planes for charge collection (i.e. without MSGCs) could be of great advantage for the implementation of a number of future X-ray astronomy missions. They may fulfill a vision of X-ray detectors with moderate cost, large format, and excellent position resolution, while retaining the high quantum efficiency of the noble gases for recording incident X-rays.

In moving from particle physics applications to the space environment, several issues immediately arise. The use of GEM detectors in space will be most practical with sealed units in contrast to the gas-flow detectors used in ground-based laboratories. All of the materials used in the detector, including the GEM foils, the GEM mounts, and the readout planes, must not contribute contamination via out-gassing. The detectors must be able to survive the launch and space environments and operate reliably for many years. Thus, the design must consider the vibration, acoustic, and shock loads of a typical mission and also the requirement to remain under tension and perform reliably over a substantial range of ambient temperatures. The detectors must also feature readout schemes involving relatively simple electronics that consume little power, e.g., a few watts or less per detector, in order to be efficient and affordable for small missions.

It is highly desirable that the detector system feature a readout plane design and electronics concept that are clearly appropriate for SMEX and MIDEX-class missions. One must first consider whether the readout paradigms used in the particle physics versions of GEM detectors are suitable in this regard. For use in particle physics



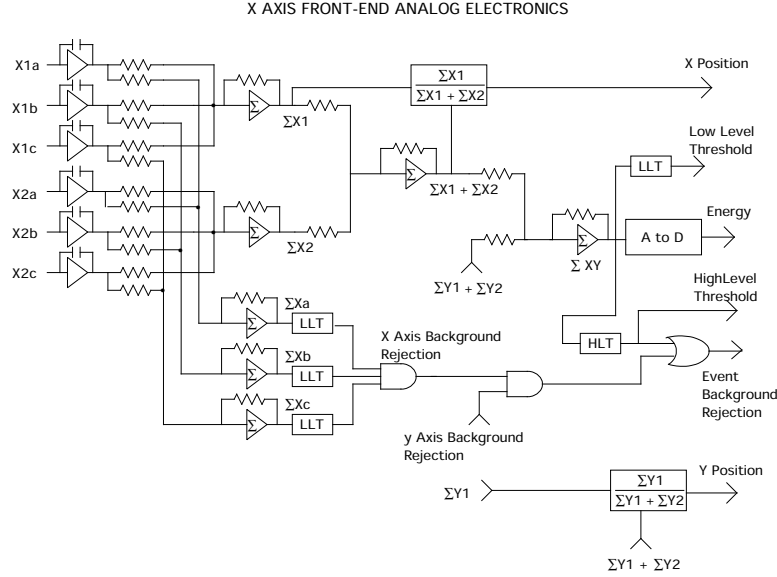
**Figure 2.** Schematic drawing showing the configuration of a wireless strip readout plane. The 6 wide bars indicate resistive strips.

experiments, each strip in a surface-mount readout plane is connected to an electronic measurement chain. This scheme requires a very large number ( $> 1000$ ) of measurement chains. A highly integrated readout system for microstrip-type detectors has been developed in Europe for use at CERN and other accelerator facilities. The system includes the use of a single chip, called the “HELIX 128”, with 128 low noise charge sensitive preamplifiers and control circuitry that can be read out in pipeline fashion. There is also a compatible “SUFIX” (SUPport chip FOR helIX) chip that includes an analog to digital converter designed to interface directly with the HELIX 128 chip. The output from the SUFIX chip is a serial stream of digital signals representing the charge detected in each of 128 strips or channels. This technology is promising for future space applications of gas detectors, but the electronics package for an instrument comprising more than a few detectors may require a powerful CPU manager, a large amount of power, and a relatively large volume. While these consequences may not be inevitable, the economic application of this technology may not be optimal for space borne missions at the present time.

The readout concept we intend to develop uses an array of electrodes similar to those previously used by the developers of the GEM.<sup>13</sup> However, rather than connecting each individual electrode to a preamplifier and measurement chain, as is the practice in particle physics experiments, we would connect the preamplifiers and measurement chains to groups of anodes via resistive strips. This technique is analogous to the method for determining event positions that was successfully implemented for the RXTE ASM. Below, we describe our approach in further detail.

We baseline a readout plane consisting of orthogonal arrays of conductors for charge collection plated onto a substrate (see Figure 2). The “X” and “Y” grids are isolated from each other by a thin insulating layer. The X grid traces are arranged into three groups (A, B and C) in order to help characterize the spatial profile of the events in the detector. Each group is made up of multiple sets of a small number (provisionally 4) of adjacent traces; the sets of traces are arranged in cyclic fashion, i.e., ABCABC... (see Figure 2). The traces for each group are connected to a resistive strip, each end of which is, in turn, connected to readout amplifiers. The traces forming the Y grid are also subdivided into groups and connected to resistive strips. The charge produced by each event will be split among various X and Y traces and then further split between the amplifier chains at the two ends of the associated resistive strips. Signal charge that reaches each end of each resistive strip will be amplified for subsequent processing including threshold detection, background event identification, event energy and position determination, and digitization.

It is important that systems utilizing our readout and electronics concept be able to identify and reject non-X-ray background. We expect that this can be accomplished in our design by two methods. First, the total charge



**Figure 3.** A simplified schematic of the readout electronics for processing the signals from one axis of one detector.

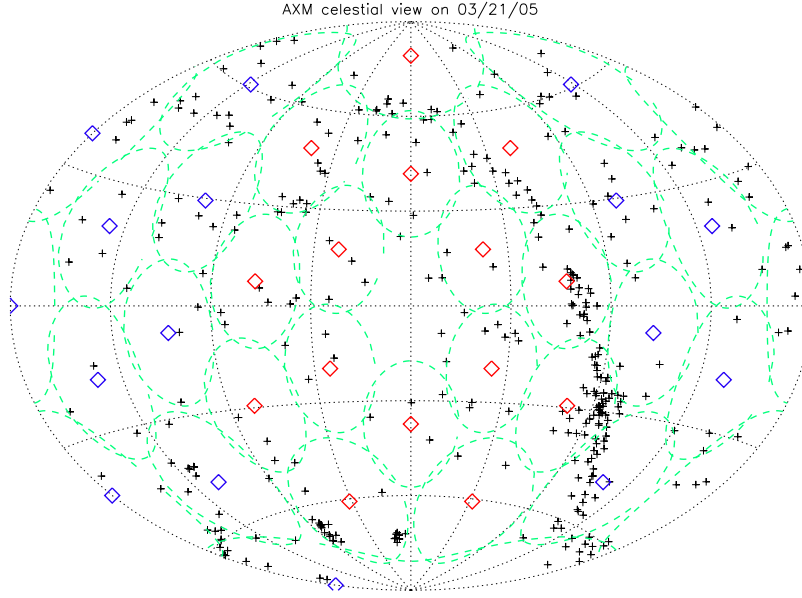
generated by most non-X-ray events will exceed a high level threshold setting. Second, energetic charged particles, as opposed to X-ray photons, will leave a long track of secondary ionization that will normally produce an extended cloud of electrons at the readout grid resulting in a charge signal being produced in many of the sensing grid traces. In contrast, an X-ray event will be more localized and produce a charge signal in only a few of the grid traces. Background events can then be rejected by identifying coincidences among all 3 of the A, B, and C outputs. We expect this approach to achieve a background rejection efficiency of 95%. A simplified schematic of the front-end and background detection electronics is shown in Figure 3.

### 3. OBJECTIVES FOR AN ADVANCED X-RAY MONITOR

The X-ray sky is extremely variable. This variability ranges from  $<1$  ms to days to years. Intensity changes by ten orders of magnitude have been seen in some soft gamma-ray repeaters (SGRs), while even the most persistent X-ray binaries and active galactic nuclei (AGN) commonly vary by a factor of two or more. Space missions in the last decades generated productive science applications related to X-ray monitoring. Recently, X-ray source variability has been witnessed with unprecedented clarity during the 4.5 years of observations with RXTE (launched 12/95). This mission includes a scanning All Sky Monitor (ASM) and pointed instruments that provide  $1 \mu\text{s}$  time resolution. Additional insights have been gained from the Italian-Dutch *BeppoSAX* Mission (launched 5/96). Scientific advances from these observatories substantiate the perspective that high energy astrophysics often requires a joint consideration of temporal and spectral variability and a strong commitment to multifrequency observations.

In a recent NASA opportunity for new missions in the Small Explorer (SMEX) class, we proposed an “Advanced X-ray Monitor” (AXM) as a concept that synthesizes the capabilities of GEM detectors and the scientific advantages of all-sky viewing. The AXM would generate self-contained science investigations and will further provide invaluable and rapid guidance to other programs for scheduling observations and for interpreting results. The AXM data and results would constitute a public archive, and community science programs would be funded via competitive grants administered through NASA’s Astrophysics Data Program and Astrophysics Theory Program. The AXM has 2 primary design goals:

- To observe nearly the entire sky, continuously, so as to measure temporal and spectral properties of outbursts and flares which last from seconds to hours,
- To monitor “persistent” X-ray sources with sufficient sensitivity to provide detailed light curves for many accreting compact objects in the Galaxy and extragalactic AGN.



**Figure 4.** Pattern of sky coverage for the 31 cameras of the AXM when the Sun crosses the celestial equator (map center) on the first day of spring. The pointing directions highlighted in red correspond to the 15 cameras oriented toward the solar hemisphere, while the 16 positions with blue highlights view the hemisphere away from the Sun. The spacecraft orientation would remain fixed except for  $\sim$ daily pointing adjustments to re-align the solar axis with the Sun.

The AXM concept consists of 31 cameras, each consisting of a GEM detector mounted below a two-dimensional coded-mask aperture. The camera fields of view (FOV) would combine to cover the entire sky, except for a small exclusion zone in the direction of the Sun. The cameras would operate in the range of 1.5 to 12 keV, and they are designed to achieve sensitivity to sources that appear for times as short as 1 ms as well as sources that persist for many years. The baseline AXM detection capability is  $\sim 300$  mCrab ( $5\sigma$ ) in 1 s and  $\sim 1$  mCrab ( $3\sigma$ ) in 1 day, where 1 mCrab is  $2.4 \times 10^{-11}$  erg cm $^{-2}$  s $^{-1}$  at 2-10 keV. The AXM would be launched into a  $\sim 600$  km equatorial orbit. Each “good” event would be telemetered to the ground with 0.3 mm spatial resolution,  $122\mu$ s temporal resolution, and 64 channels of spectral resolution, providing enormous flexibility for scientific analyses. The design lifetime is 3 years, with substantial probability for longer operating lifetime.

The mounting orientations for the 31 AXM cameras are shown in Figure 4. They resemble the 32 faces and vertices of a soccer ball, with 1 camera eliminated (center of figure) to avoid the saturating effect of the Sun’s X-rays. The chosen epoch for Figure 4 is the vernal equinox; the Sun is at the center of the figure (position 0.0, 0.0). The 15 camera centers highlighted in red point in the solar hemisphere, while 16 in blue view the opposite hemisphere. The “+” symbols show the positions of 334 sources currently monitored with the *RXTE* ASM; these cluster in the Magellanic Clouds and along the Galactic plane. The dashed green lines for each camera indicate offset angles of  $20^\circ$ , which corresponds to half transmission through the coded mask. The sum of the transmission contributions produce approximately uniform exposure over the celestial sphere, excluding only the  $\sim 3\%$  region near the Sun, as well as  $\sim 30\%$  of the sky blocked by the Earth. A summary of design specifications and sensitivity estimates for the AXM are given in Table 1.

The routine on-line data analysis would consist of three stages. First, the intensities of catalogued sources will be determined as a function of time (for several “standard” time intervals) together with confirmation or correction of the aspect of the cameras. Second, searches for new sources will be conducted. We would use cross-correlation imaging techniques, e.g. at 100 s and 1-day time intervals to determine rough locations and intensities. The data selection intervals would then be optimized to yield precise source positions. Third, the data analyses would then be iterated to re-derive the intensities of previously known and new sources to produce the final AXM results for a

permanent public archive.

The results of the preliminary, on-line analysis for X-ray intensities and new source alerts would be disseminated via the internet within  $\sim 30$  minutes of each ground station pass, in a manner similar to what is done for RXTE ASM data. The final results would be made public as soon as practical, e.g. 1 week after the observations are made.

**Table 1.** A summary of AXM characteristics and performance estimates.

Number of cameras	31
Energy Range	1.5–12 keV
Overall Field of View	97% of $4\pi$ sr
Non-Earth-blocked Field	64% of $4\pi$ sr
Operating Duty Cycle	95%
Nominal Camera Size	$20 \times 20 \times 32$ cm
Spectral Resolution	$\sim 20\%$ at 6 keV
Time Resolution	$122\mu\text{s}$
Net Active Detector Area	$200 \text{ cm}^2$ per camera
Area through the coded mask	$70 \text{ cm}^2$ per camera
Mask Area	$20 \text{ cm} \times 20 \text{ cm}$ .
Mask Height above Detector	27.5 cm
Mask element (projection)	1 mm (12.5 arcmin)
Position bins	$512 \times 512 \times 0.3$ mm
Uncertainty, bright sources	1 arcmin
Camera 100% transmission	$5.2^\circ$ radius
Camera 50% transmission	$20.0^\circ$ radius
Total Camera FOV	$32.5^\circ$ radius
X-ray background per camera	210 c/s
Count rate for Crab Nebula	170 c/s
Flare detection limit, 1 s	new source: 425 mCrab
Flare detection limit, 1 s	known source: 300 mCrab
Detection limit, 1 day	known source: 0.8 mCrab

#### 4. AXM SCIENCE PROGRAM

The AXM design would address many scientific objectives that can be conveniently divided into three broad themes:

- **The science of jets and other cosmic explosions**

Several types of rare, explosive events produce X-ray emission on timescales from seconds to hours, e.g. ejections of relativistic jets in microquasars<sup>16,17</sup>, flares in fast X-ray novae,<sup>18</sup> flashes from SGRs,<sup>19</sup> gamma ray bursts,<sup>20</sup> and giant flares from active coronae.<sup>21</sup> There is a common thread among these diverse systems: these dramatic events are infrequent and unpredictable, and scientific progress is impeded by the difficulty in gaining detailed observations. With continuous viewing of 70% of the sky and  $75 \text{ cm}^2$  of active detector area, the AXM offers substantial improvements for the capture rate of rare, explosive events. For comparison, the RXTE ASM cameras view 3.9% (FWHM) of the sky with typically  $\sim 20 \text{ cm}^2$  of effective area, and with a duty cycle of  $\sim 40\%$ , imposed by the satellite orbit which traverses the SAA and other regions with high particle flux. The AXM also opens substantial opportunity for the discovery of infrequent, brief outbursts of types hitherto unknown.

- **Long term spectral and temporal evolution of persistent sources**

Continuous all-sky viewing also provides long exposure times that may help to address science issues that involve evolution on timescales from several hours to several years. In terms of both the density of coverage and the sensitivity threshold per day, the AXM design offers large improvements over the RXTE ASM, e.g. a six-fold increase in signal to noise per day for faint sources, with reduced vulnerability to systematic errors related to, e.g., the ASM's limited anode number, time-dependent calibrations, and noisy regions of the satellite orbit. The AXM would produce X-ray light curves which show variability in incredible detail, e.g. tracing the spectral evolution of black hole binaries,<sup>22</sup> or tracking the excursions of accretion flow in low-magnetic-field neutron star systems.<sup>23</sup> Spin changes would be measured over long baselines for *all* accretion-powered pulsars to test evolving physical models for accretion torques and disk-magnetosphere interaction.<sup>24,25</sup> Pulsar spin changes in the anomalous X-ray pulsars would test the “magnetar” hypothesis and the possible association with SGRs.<sup>26,27</sup>

The AXM would substantially contribute to the science of Active Galactic Nuclei (AGN) in several ways. There would be daily measurements of  $\sim 15$  BL Lac objects brighter than 1 mCrab, with sensitivity to major eruptions (e.g. factor of 5 or more) for  $\sim 80$  other BL Lacs with mean flux  $\gtrsim 0.3$  mCrab. Since the X-ray outbursts signify synchrotron emission that is correlated with inverse Compton emission at much higher frequencies,<sup>28,29</sup> this X-ray monitoring capability would greatly enhance the productivity of the rapidly evolving TeV observatories (Whipple, HEGRA, CAT, etc), while the instruments expected during the AXM era (VERITAS, HESS) are again  $\sim 50\times$  more sensitive. For emission-line AGN, multifrequency studies would be supported with frequent X-ray measurements of dozens of objects in several subclasses. Furthermore, the utility of using long-term X-ray power spectra to provide estimates for the mass of the central black hole would be explored in earnest for the first time.<sup>30</sup>

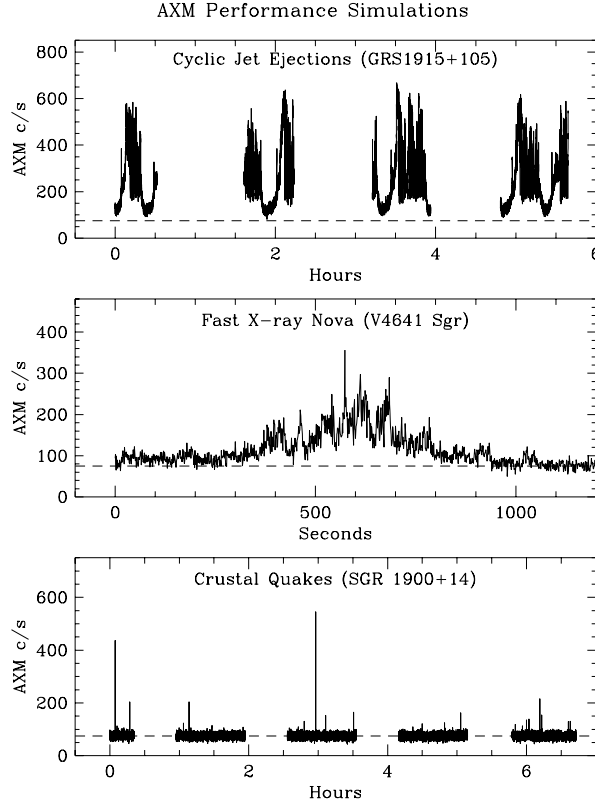
- **Empowerment of other observatories and multifrequency science**

All sky monitors provide alerts for new X-ray sources and for major changes in known sources. These services provide observing opportunities that strongly enhance the productivity of space missions and ground based programs involved in high energy astrophysics. In the 2003-2007 time frame, the X- and gamma-ray missions will include *Chandra*, *XMM*, *INTEGRAL*, and *GLAST*, and it is extremely important that these observatories conduct their pointed observations with full awareness of the opportunities that all-sky viewing would provide.

There are also substantial ground based programs that are intimately tied to the data from X-ray monitors. These include the TeV observatories, noted above, the Greenbank Interferometer (which monitors high-energy sources in the radio band), and several optical programs involving both university consortia and the growing networks of amateur optical astronomers. There are also sophisticated plans for robotic observatories (e.g. Perugia, Torino, Sarah, La Palma, Liverpool Telescope) that can contribute productive programs for optical or IR monitoring of X-ray sources in outburst.

The advantages of combining pointed X-ray observations with all-sky monitoring and ground-based support are abundantly clear. Scientific productivity is strongly enhanced by rapid response to outbursts, state changes, etc. Alert criteria can be tailored to fit the detailed requirements of individual research programs. Furthermore, as shown by the RXTE ASM, the global views of source behavior seen in long-term X-ray light curves are widely used to provide context for, and thereby enable more secure interpretation of, the pointed observations.

We briefly illustrate the performance of the AXM for 3 types of explosive X-ray sources mentioned above. We have taken the X-ray light curves from the RXTE PCA (1 s bins) for the microquasar GRS1915+105,<sup>17</sup> the fast X-ray nova V4641 Sgr,<sup>18</sup> and the SGR 1900+14,<sup>19</sup> and then simulated what the AXM would see from these sources. We scaled the PCA count rates to an effective area of 70 cm<sup>2</sup> (4.8 % of 1 PCU), added a background count rate of 75 c/s, and then imposed statistical noise on each bin. This is tantamount to having a dominant source in a 20° circle on the sky, and then selecting only the detector positions that are open to the source (and the diffuse background) through the coded mask. These detector positions are generally located in two cameras. The results are shown in Figure 5. It is clear that the AXM contributes rich temporal information applicable to the science of jets and other types of cosmic explosions.



**Figure 5.** Simulations (including counting statistics) of the performance of the proposed AXM, scaling the PCA light curves for effective area and adding a contribution from the diffuse X-ray background (dashed line). Each light curve, shown at 1 s time resolution, is derived from the sum of detector positions that view the source through the coded mask.

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